American Journal of Environmental Sciences

Original Research Paper

Monitoring the Rate of Change at Urualla Gully Erosion Site Using GIS and Remote Sensing Methodology

Sylvanus Iro

Department of Geography and Environmental Management, Imo State University, Owerri, Nigeria

Article history
Received: 25-09-2023
Revised: 24-11-2023
Accepted: 12-12-2023

Email: sylvanusiro@gmail.com

Abstract: Urualla gully erosion was monitored using GIS and remote sensing in Urualla, Ideato North Imo State Nigeria. The objective is to calculate the rate of change of Urualla gully erosion and identify measures to control its growth. The study's data came from primary and secondary sources, such as Google Earth imageries, DEMs, and in situ measurements. Google Earth was used to vectorize and digitize the gully by using a slider tool to get the various years. According to measurements of the Urualla gully, its area has steadily increased. Over time, the gully has shown to be 137,876, 144,897, 164,876, 184,236, 200,000, and 203,065 m^2, respectively. This shows that gully factors like high runoff, vegetation removal and refuse dumping on drainage channels have been active near the gully site. There is an urgent need for integrated landscape planning due to the loss of land due to gully erosion, urban expansion, industrialization, and further human activities on the land. Various best land low-cost strategies and management techniques can prevent and tackle gullies, which have become too severe to remedy. When gully erosion is still in its infancy, control measures are most effective in stemming it. This method of monitoring gullies applies to any area with a similar environment and scenario, whether it be national or international, using GIS and remote sensing.

Keywords: Urualla Gully, Erosion, Monitoring and GIS and Remote Sensing

Introduction

In Urualla, gully erosion threatens roads, people, communication infrastructure, and precious land. It necessitates further research and costly control methods. The growth of concreted areas in towns has increased volumes and the resulting runoff velocity has tended to make many Nigerian towns more vulnerable to the formation of gullies (Iro, 2020). Increased pressure on land may result in an expansion of the utilization of urban land expansion of the utilization of urban land to the stream channels flood plain and confinement of the stream to artificial channels when the majority of the available land in an urban region is built up.

Gully erosion is a major problem; however, the situation is getting worse annually. The primary contributing elements to Urualla's gullying problem are undoubtedly the town's low topography, sloppy relief, undulating landscape, river channel, soil composition, and infrastructure development combined with population growth (Iro, 2021). Human habitation and their various activities are associated with the gradual destruction of the vegetable cover. As a result, the balance between physical and biological components of the environment is susceptible as a result of the both structure and texture of the soil. The erosion rate in the area has been accelerating, raising concerns among residents. As well as causing personal property damage, gully erosion is causing structural and functional damage to infrastructure in the stream channel, including culvert outlets and roads. It has been tried to address the issue at a few crucial locations by the state government. Gully erosion should be monitored as an environmental concern because the economic realities and engineering control measures have fallen short of public expectations because of little knowledge about the issue.

Despite the small number of research conducted, many of them focus on the genesis, consequences, and evolution of gullies in the environment. There has been no effort to map and monitor gully erosion using remote sensing and GIS. It is necessary to combine detailed field observation and process-based knowledge of contemporary gulling with GIS techniques, to reconstruct conditions leading to gully channel incision and development and infilling.

Gully Erosion as a Global Issue

"The secret to both the present and the future lies in the past" (Zhang *et al*., 2007; Argentieri *et al*., 2015). The morphology of gullies provides evidence of changes in environmental impacts like land cover and rainfall patterns over time (Poesen, 2011). Gullying and soil erosion are not exclusively modern phenomena associated with industrial land management. Gullies have caused difficulties throughout history as evidenced by documented cases. From the commencement of human habitation around AD 300/600 until AD 1280, Okeke *et al*. (2012) claim that agricultural activities on the Poike peninsula (in the northwest of Easter Island) were characterized by sustainable land use and conventional agroforestry through stratigraphic study. Soil erosion occurred when slash-and-burn methods were used to destroy the woods on Poike, which was primarily home to the endemic palm Jubaea, about the year 1280. Sheet erosion persisted until the 20th century on the top slopes of the volcanic peninsula due to intense farming.

In Europe, Dotterweich and Dreibrodt (2011) found that the most dramatic periods of soil erosion took place in the first part of the fourteenth century. More than 500 years have passed since central Europe's agricultural history began, with the first records of land removal and deforestation coming from Germany in the middle of the 18th and early 19th centuries (Desta and Adugna, 2012). Hugh Hammond Bennett became a national spokesperson and supporter of soil conservation and soil erosion research after serving as a soil surveyor for the USDA Bureau of Soils from 1903 until the 1920s (Di Stefano and Ferro, 2011). Bennett raised awareness of the erosion issue among the general public and in politics. Congress first authorized $160,000 in 1929 to support soil erosion research because of the disastrous "dust bowl" drought, wind erosion, and dust storms. in the Great Plains (Di Stefano and Ferro, 2011).

Comparatively speaking to other continents like Europe and America, Africa is still understudied (David, 2012). In most cases, there has been very little archaeological study done, very few records have been examined from an earth perspective, and oral histories of cultures and their environments have not been thoroughly gathered and examined (Chikwelu and Ogbuagu, 2014). Governments attempted to compel farmers and peasants to use farming methods that had been approved by science throughout the colonial era. As a result, the shifting cultivation practice was abandoned, which had been giving the soil extensive fallows, making the soil unstable and encouraging the development of soil/gully erosion (David, 2012).

Due to the established conditions brought about by European dominance, gully erosion has been rapidly advancing throughout Africa for many generations. As a result, it is currently considered a critical issue and has gained urgent importance. Prior to recently, there were not as many people living in Africa as there are now, which has led to gully development, which has now risen due to natural processes (Anejionu, 2013).

Located in Central Africa's tropical Congo basin rainforest, the Democratic Republic of the Congo experiences a typically hot and muggy climate (Ornstein and Lyhagen, 2016). According to Patrick (2013), gully erosion was first seen during the colonial era, which led to the development of mechanized agriculture, continuous logging, and solid mineral exploitation. Early in the 1970s, the western plain beside the Malebo Pool was completely urbanized, and the built-up zones. Early in the 1970s, the western plain beside the Malebo Pool completely urbanized and the built-up zones began to extend into the hilly terrain to the south, Ohlmacher *et al*. (2007) detected the first indicators of gullying in Kinshasa. Caillie linked the vertical incision of drainage lines with slopes steeper than 0.12-0.25 mm^{-1} According to Obiadi *et al*. (2011) findings, most gullies originate from the bare slope where the vegetation cover has been eliminated and the convergence of runoff creates a gully head. Southeast Nigeria and the Democratic Republic of the Congo have the same land and climate. Figure 1 provides a summary of the current state of soil degradation worldwide. According to the Dionne (2010), as of 2006, the percentage of degraded land worldwide ranged from around 16% in Europe to 30% in North America, 35% in South America, and 45% in Africa. Rain-fed agriculture and rangeland accounted for the greatest portion of degraded land. According to the Dionne (2010) first international assessment of soil erosion done between 1961 and 1991, there was a consistent decrease in cropland, resulting in a global reduction in usable soil area of between 20 and 30%. Global farmland area (hectares) per person decreased, for instance, from 0.6 ha/person in Africa to 0.2 ha/person in North and Central America, from 1-0.8 ha/person in Asia, from 0.4-0.2 ha/person in South America and from 0.4-0.35 ha/person in Europe.

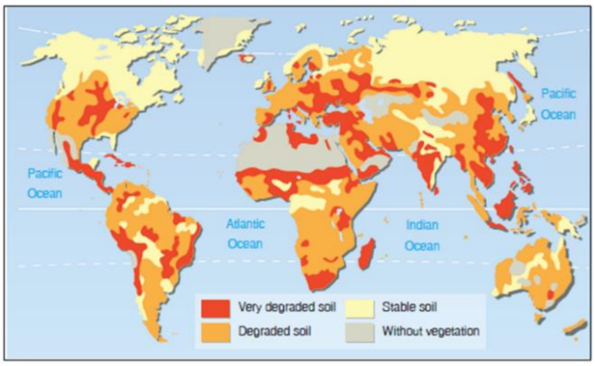

Fig. 1: Areas of concern for soil degradation (Iro, 2021)

DOI: 10.3844/ajessp.2023.118.126

Due to wind or very heavy rainfall, Sub-Saharan Africa has severe environmental deterioration, which causes desertification, droughts excessive runoff, and soil erosion. The crop area in southeast Nigeria was classified by the Dionne (2010) as being more susceptible to soil degradation, particularly gully erosion. Gully erosion has resulted in significant soil loss, the destruction of lives and houses, a reduction in local agricultural output, and the forced relocation of communities whose ancestral homes are unsafe or unsustainable. These claims are made by Chin (2013).

The ecosystem and environment in the southeast of Nigeria are negatively impacted by anthropogenic activities such as resource extraction and exploration. There formerly was a dense forest in southeast Nigeria, home to native tree species such as Iroko, bamboo, and mahogany (Asner *et al*., 2010). One major effect of resource exploitation is often the loss of vegetative cover. The region is rife with illegal operations that violate conservation regulations and the consequences are visible in the environment due to weathering and erosion-induced soil degradation.

Statement of Problem

Notwithstanding a number of studies conducted by experts, the destruction brought about by gully erosion in southeast Nigeria is extremely inadequately measured. The Urualla gully has been slowly taking up farmlands, and houses, and people who go close to the edges fall in due to cave-ins. The gully's expanding size has forced many households to leave their homes and relocate elsewhere. The gully is unpredictable since experts have not been able to fully understand its nature as it has grown over time. A technique that permits a regional analysis is needed for this study and it can be achieved by using the medium-resolution, low-cost remote sensing data that this thesis suggests. By measuring the gully's size and tracking its change over time, one can gain insight into the gully's dynamics and evolution. This study aims to provide preventive methods that can be used to lower the need for future intervention and slow down the rate of growth. This approach was used by Iro (2021) to measure gully erosion sites for recommendation to the various communities for appropriate remediation measures. Socio-economic problems caused by gully erosion have made some inhabitants in Urualla to be cut off from the rest of the town. This study when undertaken will help in monitoring and prevention of the gully expansion for effective reclamation measures and reconstruction.

Study Area

Imo State, Nigeria's Ideato North Local Government Area is seen in Fig. 2. Originally known as Ideato Local Government, it was split into Ideato North and Ideato South Fig. 4 after being established in 1976. Urualla is home to its administrative headquarters. Ideato North can be found between 5° 86’ N, 6° 59’ N, 6° 60’E, and 5° 86’ N, 7° 13’ covering a land area of approximately 190 Km^2 as shown in Figs. 2-5. It is typified by coexisting land cover and use types that are primarily impacted by gully erosion. The research region is located in a belt of humid tropical rainforests with an average annual rainfall of 1800-3000 mm. Topography, which ranges mostly from flat to swamp-like parts, relief, and lithology, along with anthropogenic factors like abandoned industrial sites, control the vegetation in the area. Its length is about on average1,998 m; the average width at the top of 16 m and the depth of 27.5 m Slope is between 2-7°. The Queen of Apostolic Parish Catholic Church Road Junction, which connects Obioha and Obodoukwu Road, is the entry point. A significant crustal depression at the gully's mouth may have formed as a result of historic tectonic activity or erosion processes.

Fig. 2: Map of Nigeria highlighting Imo state

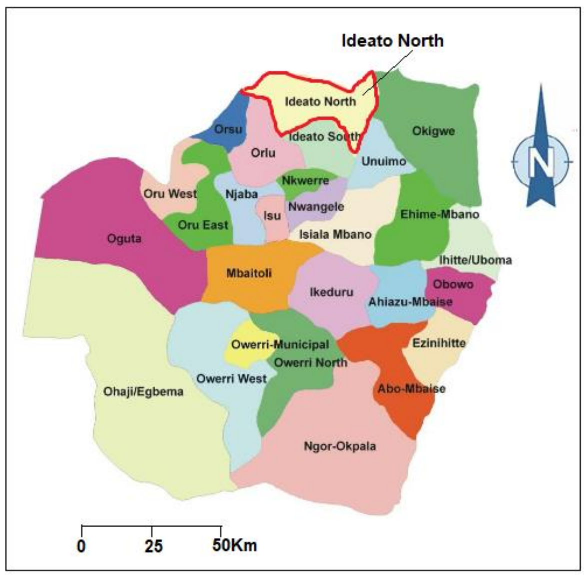

Fig. 3: Map of Imo state highlighting Ideato North local government area

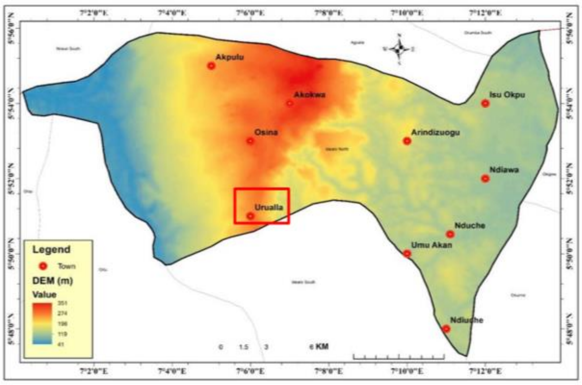

Fig. 4: DEM of Ideato north local government area showing Urualla

Fig. 5: Google Earth image of Urualla Gully site (Source: Google Earth)

Materials and Methods

Using remote sensing and GIS methodology to determine the causes of gully erosion and associated rates of change in Urualla, was conceived out of the effect of the gully development on the people and the communities' inability to develop answers to the current situation. Both spatial and non-spatial data sets are used in this investigation. GIS and remote sensing were used because the study traced and measured the gully from the past years and also, the gully caves in at any time which does not allow ground measurement and can only allow the prescribed method to get the desired result.

Categories of Data

Data used are categorized into primary and secondary data.

The information obtained via field observation (ground control points) and measurements which comprise vector and raster formats produced by on-screen digitization and classification make up the primary data. The information on gully erosion that is currently available, gathered from literature reviews and other sources, makes up the secondary data.

Ground control points were established in four places:

- The coordinates of four ground control points were picked:

  1. Icheku tree (Lat. 5°52'11.46"N and Long. 7° 3'12.97"E)
  2. Iroko tree (Lat. 5°52'21.07"N and Long. 7° 3'45.22"E)
  3. Palm tree1 (Lat. 5°52'13.94"N and Long. 7° 3'45.49"E)
  4. Palm tree 2 (Lat. 5°52'3.02"N and Long. 7° 3'17.80"E)

  These clues helped determine the gully's exact position in the imagery and its measurements
- The interval in the measurement was 2 years to record appreciable growth
- For the purposes of this investigation, the remote sensing data used came from Google Earth images from December 2012, 2014, 2016, 2018, 2020, and 2022. The reason for the choice of December was to make sure that the rainy season for the year has ended to avoid taking the increase of one year to another. Again, Google imagery was used because that is the only clearer resolution available in the area
- In order to create a base map for analysis, Google Earth images were obtained. Then, gully edges were digitalized and quantified using the polygon tool from Google Earth, spanning the first year that the data was accessible, 2012, to 2022

Data Acquisition

The imageries were acquired from Google Earth and the area of the gully was measured using a ruler tool in the Google Earth. The years of the gully were measured using Time Slider also, a tool in Google Earth.

Fig. 6: 2012 Urualla gully image (Source: Google Earth)

Fig. 7: 2014 Urualla gully image (Source: Google Earth)

Fig. 8: 2016 Urualla gully image (Source: Google Earth)

Fig. 9: 2018 Urualla gully image (Source: Google Earth)

Fig. 10: 2020 Urualla gully Image (Source: Google Earth)

Fig. 11: 2022 Urualla Gully Image (Source: Google Earth)

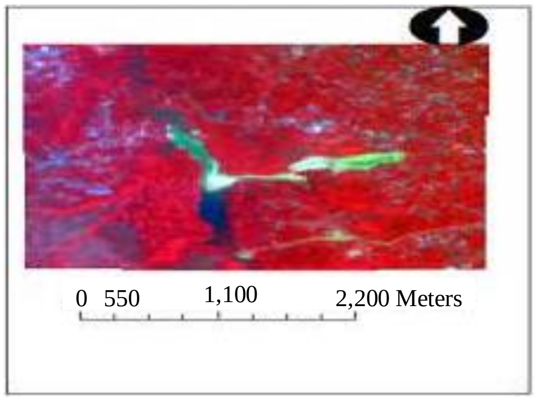

Fig. 12: Landsat imagery of Urualla Gully (Source: United States Geophysical Survey)

The imagery Figs. 6-12 was used to ascertain the location of the gully but the study did not go into using it in digitizing it and measuring because it was not clear and trees and forests cover part of the gully site in the imagery.

Data Presentation and Result

This study processes the satellite data using GIS and remote sensing techniques.

Data Analysis

This study tried to digitize, measure, and calculate the rate of change of the gully from 2012-2022, as can be found in the methodology section, Table 1 shows how the gully has been developing starting from the commencement of this study, 2012 when the rate of change of Urualla Gully was smaller compared to the rate of change in 2022 when it has increased in size. From 2012, the gully was 137,876 m^2 in area. The gully developed in 2014 and 2016 to 144,897 and 144,897 m^2 respectively. The gully has increased in size in 2018, 2020, and 2022 to 184,236, 200,000, and 203,065 m^2 respectfully. This has shown a difference of 0 m^2 from 2012 when the research work started to when it was 3,065 m^2 in the year 2022 measured in this study.

DOI: 10.3844/ajessp.2023.118.126

Table 1: Area covered in square meters by Urualla Gully from 2012-2022

Years	Gully area in m^2
2012	137,876
2014	144,897
2016	164,876
2018	184,236
2020	200,000
2022	203,065

Table 2: Rate of change of Urualla Gully site from 2012-2022

Years	Gully area in m^2	Rate of change in m^2
2012	137,876	0
2014	144,897	7,021
2016	164,876	19,979
2018	184,236	19,360
2020	200,000	15,764
2022	203,065	3,065

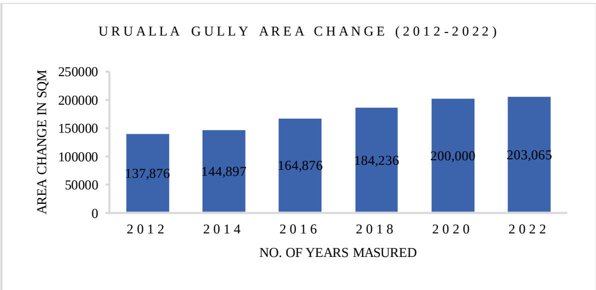

Fig. 13: Bar Chart showing the rate of Urualla Gully change

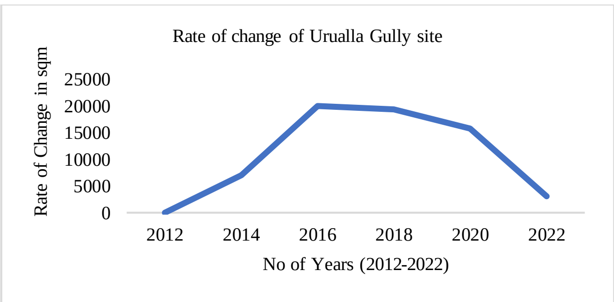

Fig. 14: Line graph showing the rate of change of the Urualla Gully site

Summary of Analysis

Rate of Gully Erosion (Gully Changes between 2012-2022)

From the Figs. 13-14, the bar chart and graph, show that the highest rate of change was in 2016 and 2018 with the rate of change of 19,979 and 19,360 sqm respectively. This could be attributed to high rainfall data in those years and the rate of interference by the communities around the gully site. Once more, the act of disposing of waste along gully channels may cause it to progressively build around the channels. When precipitation occurs, this interaction between the debris, the gully channels, and the running water may cause the gully wall to gradually be undermined. The lowest rate of change was in the year 2022 with the rate of change of 3,065 sqm. This lowest change could be the communities are taking measures to plant trees, divert runoff, and stop excavating sand around the gully site. It is observed that the soil type in Urualla which is Ferralic Arenosols, which is Unconsolidated infertile soils results in sands that are deposited by the wind or water that have very little nutrient reserves. Additionally, these weathered soils have red and yellow hues that are caused by the buildup of metal oxides, especially aluminum and iron (Iro, 2020). This type of soil tends to encourage gully formation and development. Additionally, inadequate or nonexistent systems for collecting Runoff of water and its subsequent utilization, surface runoff drainage, or the installation of primary (trunk) drains, division, and interception could all have an impact on how quickly gullies develop and evolve.

Discussion

Factors Leading to the Increment of Gullies

According to fieldwork, gully erosion happens across the Urualla village. Although natural causes account for the majority of erosion issues, human ignorance and inadvertent behavior are increasingly being blamed for the magnitude and severity of these problems (Iro, 2021). Despite the progress made in technology, such as drainage canals (Nekatet, 2006), run-off catch pits (Iro and Acholonu, 2020), and land-use planning Brolly and Iro, (2016), gully erosion is still a significant issue in the area. Scholars have noted that the geology (Nachtergaele *et al*., 2002), geomorphological, and rainfall runoff context of the area all play a major role in gully erosion. There is also consensus that although these naturally occurring circumstances are ideal for gully erosion, human activities like land-use change and pollution make them worse (Verachtert *et al*., 2011). Each of these incidents contributes to the erosion of gullies (Egboka *et al*., 1990).

The rate of gully erosion depends on the runoff, the drainage area; soil characteristics; the alignment, size, and shape of the gully; and the gradient of the gully channel. The following could also be responsible:

(a) Land use pattern of Urualla: The area's difficulties with gully erosion have undoubtedly been made worse by the study area's land use pattern, which includes both infrastructure development and population growth. Increased pressure on land may result in the extension of urban land use to stream channels, flood plains, and the confinement of streams to artificial channels when the majority of the available land in an urban region is developed

(b) Rainfall pattern of Urualla: Rainfall is one of the main factors, along with other factors like population growth, unplanned land use, deforestation, etc., that contribute to the area's increased gully growth because the area is primarily composed of bare surfaces and areas with less vegetation, which produce more runoff than an area that is vegetated. According to Ogbodo *et al*. (2008); Ofomata (2009), a rainfall event is considered erosive if the height of the precipitation equals or exceeds 13 mm per hour or the intensity of the rainfall. Rainfall is one of the main factors, along with other factors like population growth, unplanned land use, deforestation, etc., that contribute to the area's increased gully growth because the area is primarily composed of bare surfaces and areas with less vegetation, which produce more runoff than an area that is vegetated. According to Ogbodo *et al*. (2008); Ofomata (2009), a rainfall event is considered erosive if the height of the precipitation equals or exceeds 13 mm per hour or the intensity of the rainfall in 15 min is equal to or more than 6 mm. This data implies that gully erosion rises annually as a result of intense rainfall that quickly saturates the soil and causes downcutting

(c) Soil: Soil has been attributed as the primary driver of gully formation. Although Ogbodo *et al*. (2008) ascribe gully erosion to physical forces, they also propose that the structure and texture of the prevailing soil have a significant impact on the erosion's severity

The soil properties of Urualla are easily weathered because of not much vegetative cover to reduce interception and infiltration.

The power and volume of the water impact and erode the loose, bare soil gradually, creating a deep, wide ravine when heavy rain falls directly on it.

(d) Slope: One of the primary determinants of gully erosion is the slope gradient; Ofomata and Phil-Eze (2001) highlights the significance of slope by demonstrating that the gullies under study are situated near the foot of hills or slopes. Compared to flat soil, land with steep inclines is more susceptible to water erosion.

(e) Poor Construction: According to the Nigeria erosion and watershed management project, improper drain termination during road building is to blame for more than 90% of gully erosions in Nigeria (Ofomata and Phil-Eze, 2001)

The majority of Nigerian civil contractors disregarded the rule stating that drains from new roads must be appropriately ended at natural streams and other lower catchment areas rather than a few meters from the side of the road. These modifications mean that some of the surrounding roads and buildings will be affected over the period of the next six years, forcing some residents to relocate.

Summary

This study evaluated the use of GIS in tracking gully erosion in Urualla. For over ten years, the Urualla community has been threatened by gully erosion, which has resulted in numerous fatalities, immense suffering, and a threat to public utilities and transportation in the study area and its surroundings. Based on these findings, the study concluded that several factors, including inadequate or poor drainage channels, improper waste disposal that encourages people to use drainages and gully channels as places to dump refuse, increasing bank erosion and flooding, and other issues related to the environment and humans, such as demographic stress on land and environmental degradation, may have contributed to the abrupt increase in gully rate of change from 2012-2022.

Conclusion

In Urualla Gully, the numerous gully developments, the inaccessibility of some, and the communities' needs led to the notion of determining the causes of the gully and its rates of change powerlessness to find solutions to the widespread issue in the study area. The methodology used was remote sensing and GIS. The remainder of the developmental study was conducted at Imo State University in Owerri, while the fieldwork was conducted in Urualla Ideato North, Imo State, Nigeria. The Urualla Gully Site was digitized and vectorized as part of the study project and its rate of change was determined using satellite pictures taken over a ten-year period. Enough information was gathered over the course of this extensive data-gathering and analysis process to determine the rate of gully change, its historical development, and the years with high and low rates of change.

Recommendations

In the context of the purpose of this study is to assess the rate of change of Urualla gully erosion and identify strategies to control its growth. The following suggestion has been made about the gully erosion problem in the Urualla community. It has shown how the gully site is changing, which has contributed to the gullies' ongoing growth and the subsequent destruction of houses, roads, and other hazards to human safety and the environment at large. Thus, the following suggestions apply to the community as well as any other area experiencing a comparable issue with gully erosion:

1. The GIS-based monitoring strategy can be used in any environmental research as well as in physical or

regional geography across the state and the entire country. This can help to circumvent the gullies that cave in and gather past information about the gully

2. The requirement for integrated landscape planning is critical given the loss of land resulting from gully erosion and the growing demands placed on the land by urbanization, industrialization, agriculture, and other human activities
3. Although the gullies are too severe to fix now and will need extensive engineering work, they can be avoided and dealt with using a range of low-cost and best land management techniques. When gully erosion is still in its early stages, when sheet or rill erosion is still the predominant kind of erosion and erosion is still receptive to low technology intervention, control techniques to stem the erosion are most effective
4. In order to lessen erosive forces and lower soil erodibility, surface water flow can be decreased and sedimentation can be controlled by appropriate land use and watershed management
5. Lastly, managing urban areas through mining, building structures, and road construction can lessen the impact on the soil and prevent the formation of gullies. Because urban expansion is correlated with the quantity of gully formation and development can be decreased by controlling and regulating the use and removal of the physical environment as well as mining, both of which contribute to the establishment of open spaces

Acknowledgment

I would like to express my sincere gratitude to Imo State University, and the Department of GEM in particular for their invaluable contributions to this research project.

Funding Information

The authors have not received any financial support or funding to report.

Ethics

No direct contact with communities of individuals in the course of this research.

References

Anejionu, O. C., Nwilo, P. C., & Ebinne, E. S. (2013). Long term Assessment and mapping of erosion hotspots in southeastern Nigeria. *A paper presented at FIG Working Week*, 1-19. https://www.researchgate.net/publication/269403740

Argentieri, A, Fabiana Console, Simone Fabbi, Sapienza & A. Zuccari (2015). The past is the key to the present and the future: The Geoitaliani project of the Italian Geological Society. *Rendiconti Online Societa Geologica Italiana*, *36*: pp. 18-23. https://doi.org/10.3301/ROL.2015.135

Asner, G. P., Powell, G. V., Mascaro, J., Knapp, D. E., Clark, J. K., Jacobson, J., ... & Hughes, R. F. (2010). High-resolution forest carbon stocks and emissions in the Amazon. *Proceedings of the National Academy of Sciences*, *107*(38), 16738-16742. https://doi.org/10.1073/pnas.1004875107

Brolly, M., & Iro, S. (2016, December). Using the Landsat Archive to Monitor Gully Erosion Development, in SE Nigeria, as a Response to Land-use Classification and Environmental Variability. In *AGU Fall Meeting Abstracts* (Vol. 2016, pp. A11D-0054). https://ui.adsabs.harvard.edu/abs/2016AGUFM.A11D0054B/abstract

Chikwelu, E. E., & Ogbuagu, F. U. (2014). Geotechnical investigation of soil around Mbaukwu gully erosion sites, South-Eastern Part of Nigeria. *Jour. Appld. Geol. Geophys*, *2*(4), 6-17.

Chin, D. A. (2013). Water-resources engineering. 3rd Ed. ISBN-10: 0132833212.

David, G. M. (2012). Methodology for erosion hazard mapping of the Ashanti region Ghana. *Soil Technology*, *2*: 103-121.

Desta, L., & Adugna, B. (2012). Eastern Nile Watershed Management Project: A Field Guide on Gully Prevention and Control. *Nile Basin Initiative Eastern Nile Subsidiary Action Program (ENSAP)*, www.nilebasin.org/entro

Di Stefano, C., & Ferro, V. (2011). Measurements of rill and gully erosion in Sicily. *Hydrological Processes*, *25*(14), 2221-2227. https://doi.org/10.1002/hyp.7977

Dotterweich, M., & Dreibrodt, S. (2011). Past land use and soil erosion processes in central Europe. *PAGES (Past Global Changes) News*, *19*(2), 49-51. https://www.cabidigitallibrary.org/doi/full/10.5555/20123221019

Egboka, B. C. E., Nwankwor, G. I., & Orajaka, I. P. (1990). Implications of palaeo-and neotectonics in gully erosion-prone areas of southeastern Nigeria. *Natural Hazards*, *3*, 219-231. https://doi.org/10.1007/BF00124578

Dionne, G. (2010). Development and organisational practice: ethnography at the Food and Agriculture Organisation of the United Nations (FAO).

Iro. S. I. (2021). The Role of Transport System in Rural Development: A Case Study of Ehime Mbano Local Government Area of Imo State Nigeria. *Global Scientific Research in Environmental Science*, *1*(4):1-10.

Iro, S. I., & Achalonu, C. A. (2020). The Vectorisation and quantification of some gully sites in Southeast Nigeria to determine their extent and Rates of Gully change. *Global Scientific Journals in Environmental Science*, *8* (8). ISSN: 2320-9186.

Nachtergaele, J., Poesen, J., Sidorchuk, A., & Torri, D. (2002). Prediction of concentrated flow width in ephemeral gully channels. *Hydrological Processes*, *16*(10), 1935-1953. https://doi.org/10.1002/hyp.392

Nekatet, E. R. (2006). Monitoring Characterization and Controlling of Flood Water Erosions using Remote Sensing techniques. *Journal of Geology*, *54*(4), 298-323.

Obiadi, I. I., Nwosu, C. M., Ajaegwu, N. E., Anakwuba, E. K., Onuigbo, N. E., Akpunonu, E. O., & Ezim, O. E. (2011). Gully erosion in Anambra State, south east Nigeria: Issues and solution. *International Journal of Environmental Sciences*, *2*(2), 795-804. https://www.indianjournals.com/ijor.aspx?target=ijor:ijes&volume=2&issue=2&article=039

Ofomata, G. E. K., & Phil-Eze, P. O. (2001). Geographic Perspective on Environmental Problems and Management in Nigeria. *Jamoe Enterprises*. pp: 327. ISBN-10: 9783504959.

Ofomata, G. E. K. (2009). Basic geomorphology for Africa. *Enugu–Nigeria: Jamoe Publishers*.

Ogbodo, G. F., Akubueze, H. U., & Kogbe, F. (2008). Soil erosion in the humid tropics with particular reference to agricultural lands in North Central Nigeria. *Agricultural and Environmental Journal*, *3*. pp: 222- 240

Ohlmacher, G. C. (2007). Plan curvature and landslide probability in regions dominated by earth flows and earth slides. *Engineering Geology*, *91*(2-4), 117-134. https://doi.org/10.1016/j.enggeo.2007.01.005

Okeke, T., Ugo, M. A., & David, I. N. (2012). Gully Erosion in Agulu-Nanka Southeast Nigeria. *N-COGEB-D*, *23*, pp: 98-105.

Ornstein, P., & Lyhagen, J. (2016). Asymptotic properties of Spearman's rank correlation for variables with finite support. *PloS one*, *11*(1), e0145595. https://doi.org/10.1371/journal.pone.0145595

Patrick, A. (2013). Areas Affected by Gully Erosion in Southeast Nigeria. *Conference of Nigeria Geographers Calabar*, *12*(15), 68-77.

Poesen, J. (2011). Challenges in gully erosion research. *Landform Analysis*, *17*, 5-9.

Verachtert, E., Maetens, W., Van Den Eeckhaut, M., Poesen, J., & Deckers, J. (2011). Soil loss rates due to piping erosion. *Earth Surface Processes and Landforms*, *36*(13), 1715-1725. https://doi.org/10.1002/esp.2186

Zhang, Y., Wu, Y., Liu, B., Zheng, Q., & Yin, J. (2007). Characteristics and factors controlling the development of ephemeral gullies in cultivated catchments of black soil region, Northeast China. *Soil and Tillage Research*, *96*(1-2), 28-41. https://doi.org/10.1016/j.still.2007.02.010